# The nature of scale increase in agricultural innovation

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## *Abstract*

*Increasing the scale of agricultural innovation is needed for ending rural poverty. The issue of 'scaling up' has been debated widely, but many different approaches and definitions are being used. Resources available for agricultural research and extension are limited but taxonomies of scaling up approaches have thus far failed to distinguish between efficient and inefficient approaches. In economy, three concepts are frequently used to describe what happens when the scale of a system, a process or a component is changed: diminishing returns, returns to scale and scalability. The concept of scalability offers an advantage over diminishing returns or returns to scale as scalable solutions can be applied again and again within their horizon of relevance without having to be adapted or redesigned. A framework for understanding the nature of scale increase is proposed that describes agricultural innovation as a process consisting of four sub processes: policy, design, dissemination and use. The application of a design and the sub processes dissemination and use are subject to either diminishing returns, returns to scale or scalability. In each case, a different kind of trade-off can be expected between the effort made and the resulting increase in scale.*


## Introduction

The main challenge for ending rural poverty is scale. A plethora of technologies have been and are being developed to improve the living conditions of the rural poor and to improve the sustainability of agriculture. Many extension strategies have been developed to disseminate these technologies. Nevertheless, technological progress has still by-passed millions of rural poor. Some 1.2 billion people worldwide are living below the poverty line of consuming less than one USD a day and 75% of these people work and live in rural areas (IFAD, 2001). With 900 million rural poor, the need for large scale dissemination of innovation to improve the living conditions of rural poor is obvious.

In spite of the achievements of the agricultural sector in the past, there remain a number of serious challenges ahead. Between 1970 and 2000, agricultural development has been able to

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support a world population rise from 3.7 billion to 6.1 billion people, but the number of people who live below the poverty line decreased only slowly from 1.4 billion to 1.2 billion (United Nations Development Programme, 2005; Gapminder Foundation, 2005). The United Nations Millennium Declaration included the goal of halving the proportion of people whose income is less than one dollar a day and halving the proportion of people who suffer from hunger (UN Millennium Project, 2005). Further increases of the world agricultural production are deemed necessary as the world population is projected to increase to 8.3 billion by the year 2030 (United Nations, 2007). In addition, it is an enormous challenge to produce the food necessary in a sustainable way.

Meeting these challenges requires large scale agricultural innovation. As rural poverty has been reduced at only a low rate over the last decades, it is not likely that the Millennium Development Goal of halving the proportion of people who live below the poverty line will be reached without changing the scale at which agricultural innovation is performed. Unfortunately, a significant increase of the budgets available for research and agricultural extension are not expected. That means that other mechanisms have to be selected or developed to scale up rural innovation.

The issue of scaling up agricultural innovation and agricultural development has been debated widely but the issue has encountered a number of problems. First of all, there are many definitions of “scaling up” and there exist a number of related terms. This results in confusion. Second, there is no theory on what kind of scaling up is desirable. Prioritisation is important as there are huge challenges to be met while the available budgets are limited. Finally, it is often reported that problems arise with scaling up beyond pilot projects when the special conditions of the pilot projects are removed.

This paper discusses agricultural innovation, current approaches to scaling up and economic approaches to scale. Based on these insights, a conceptual framework is proposed. The proposed conceptual framework distinguishes four sub processes in agricultural innovation: policy, design, dissemination and use. The application of a design, its dissemination and use may be subject three types of scale increase: diminishing returns, returns to scale and scalability. The advantages of a process oriented approach is that it is applicable in a wide range of circumstances allowing comparing and systematisation of current insights on scaling up agricultural innovation. The conceptual framework proposed can be used to provide insight in the consequences of different options when decisions on scaling up are required.

## Approaches to agricultural innovation

Agricultural innovation is introducing new insights, new technologies, new organisational arrangements, new networks, new market relations etc. into economic use in agriculture. It is common practice to study agricultural innovation as a system. A system is a set of interacting, interdependent entities that form an integrated whole. An agricultural innovation system can be defined as a network of organisations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organisation into economic use, together with the institutions and policies that affect their behaviour and performance (International Bank for Reconstruction and Development / World Bank, 2006).

The concept of a system opens a wide range of opportunities for research. There are many different innovation systems, involving a great variety of actors and other entities that can all be studied. Discussions on the relations between research institutions and farmers have resulted in a debate between linear, supply driven approaches and demand driven approaches to agricultural innovation. In line with the demand driven approaches, there is a strong attention for the situation in which farmers farm, resulting in a focus on local circumstances.

Below, the differences between the linear, supply driven approaches and the demand driven approaches are presented. In addition, it is shown that there is a contradiction between locally specific circumstances and the need to innovate on a large scale.

### *Linear versus demand driven approaches*

Two kinds of approaches exist on agricultural innovation: linear, supply driven approaches and demand driven approaches. The linear, supply driven approach is the oldest and has been the paradigm through which agricultural innovation was understood for a long time. According to this model of innovation, knowledge is constructed by scientists in research institutes. The available knowledge is then transferred to farmers. Progress depends on the supply of knowledge by science. During the Green Revolution, technological packages where disseminated that contained seeds, fertiliser, plant protection chemicals and production instructions. Farmers where supposed to farm according to such recipes (Oasa, 1981). Although this model has received a lot of critique, it is still effective. A recent example is genetically modified soya bean that had been created in laboratories before it was transferred to farms.

Since the 1970s, when the shortcomings of the Green Revolution became visible, the limitations of the linear, supply driven model have been debated. Technological designs are not merely applications of scientific truths, but include assumptions about the circumstances in which the technology has to perform and assumptions on the aims of the technology. A '*horizon of relevance'* is assumed. Often, this horizon of relevance does not match the context in which smallholders farm (Van der Ploeg, 1991). Demand driven approaches try to resolve this problem by including the demands of smallholders as design criteria. Farmers are seen as active problem solvers who adapt agricultural technology to fit in their local situation instead of passive adopters of technologies designed in research institutions.

### *Large scale versus 'art de la localité'*

As a result of the demand driven approach to agricultural innovation, local knowledge or *art de la localité* is more and more seen as a crucial resource. Agriculture is the outcome of locally and regionally specific interactions between the social, economic and natural environments. Farmers' knowledge is considered crucial because it is supposed to bridge the gap between general, scientific insights and the concrete situation in the field. To ensure that the results of a research programme are relevant for farmers, farmers are sometimes considered “co-researchers” in the design of technology (e.g. Tekelenburg 2002, Röling et al 2004, Hounkonnou et al 2006). Participation of farmers is also considered crucial for dissemination of technologies, most notably in Farmer Training Schools (Van de Fiert, 2006).

There is a contradiction between approaches that focus on the location specific nature of agriculture and the need to increase the scale of agricultural innovation. A number of authors described these two perspectives as the “Contextualist Principle” which gives primacy to local needs and contexts and the “Universalist Principle” that is based on the belief that universal solutions can be widely applicable to problems (Van Oudenhoven and Wazir, 1998; International Bank for Reconstruction and Development / World Bank, 2003; Catacutan, 2005).

This contradiction may play a role in research programmes in which farmers are considered co-researchers. These programmes depend on public or donor funding. In general, governments or donors expect the outcomes of these programmes to benefit a much larger amount of farmers then the ones who participate in the pilot projects.

Often, the approach of such programmes is to perform a pilot first and to scale up later. IIRR (2000) divided the innovation process in three stages in which the first two have a pilot nature. The first stage labelled '*learning to be effective*' focusses on learning, investing in knowledge, capacity building etc. In the second stage, '*learning to be efficient*', the costs and inputs per unit of output are reduced. After these initial phases follows the scale up phase labelled '*learning to expand*'. Unfortunately, scaling up the results of such pilot projects is often problematic as these pilots rely on and create special conditions that enable farmers to adopt a number of innovations. Farmers who do not participate in such programmes generally have a much smaller “window of opportunity'.

As a solution, scaling up can be included as a design criterion or a “pre analytical choice” before a pilot is conducted. This has also been suggested by the literature on the Convergence of Sciences (CoS) Programme of Wageningen University. In the beginning of this project, Röling et al (2004) listed 6 questions that all need to be answered by agricultural research before the outcomes of this research can contribute to development. This list was created by summarising the work of Tekelenburg (2002) on a development project in Cochabamba, Bolivia. The list included the question “How can the outcomes be scaled up?”. The CoS programme was expected to answer these questions, but a few years later, Hounkonnou et al (2006) wrote “*In CoS it was a bit of an afterthought, in hindsight replicability should be ensured already in the formulation phase.*”

Fortunately, large scale rural innovations do occur in spite of the location specific nature of agriculture. In a number of cases, large scale adoption is limited to large farmers who have a larger window of opportunity. An example is the Brazilian zero tillage explosion that occurred in the 1990-ties. Adoption of the zero tillage technology among small farmers was low while it was high among large farmers (observation by the author in Paraná in December 2004). Other historic innovations were able to benefit large amounts of smallholders as well. For example the introduction of cassava to Africa or the use of chickens by Amerindian smallholders were very successful. So in practice, the contextualist and the universalist principles are not mutually exclusive.

If some scale increases are successful and others are not, the question arises “What is worth to scale up?” Before this question is answered, an overview of the current approaches to scaling up is presented.

## Current approaches to scaling up

A term that is often used to describe scale increase is *scaling up*. Unfortunately, there are many meanings of this term. According to Uving and Miller (1994), “its description is as varied as the people who have written about it”. The term is often used for increasing the number, the size, the quantity or the level of activity. For example, the World Bank may use the word 'scale up' in the context of 'scaling up investments'. During the workshop “Going to Scale” that was held in the Philippines in 2000 (IIRR, 2000), a bottom line definition of scaling up was formulated: *more quality benefits to more people more quickly more equitably more lastingly over a wider geographical area*. Nevertheless, the different meanings continue to exist and these reflect different approaches to increasing scale. Below, two taxonomies of scaling up approaches are presented. After presenting these common taxonomies, a critical reflection follows.

### *Uving and Miller*

Uving and Miller (1994) presented a taxonomy of scaling up approaches found in literature. They distinguished four types based on terms of either structures, programs, strategies or resource base:

- Quantitative
  *An NGO expands its size by increasing its number of members, replicating its programmes or projects elsewhere, nurturing the foundation and development of other organisations, aggregating with other organisations to combine resources or integrating results into existing structures and systems and in particular government structures.*
- Functional
  *Uptake of new activities by an organisation*
- Political
  *Building a political power base for furthering the goals of an organisation or organisations through the political process*
- Organisational
  *Addressing the issues of sustainability of an organisation, assuring that when the organisation grows, it is able to sustain its programs without complete dependence upon non-renewable resources (financial, technical and physical)*

Uving and Miller (1994) did not express a preference for a certain approach but valued this variety “as it allows for an analysis from a range of perspectives.”

This paper focusses on extending the benefits of agricultural innovation to more people. This is a combination of quantitative and organisational scaling up. However, functional and political scaling up may contribute to this aim as well.

### *Vertically scaling up and horizontally scaling up*

During a workshop titled *Workshop on Scaling Up Sustainable Agriculture (SA) Initiatives* that was held 22-23 October 1999 at the World Bank, it was mentioned that some people make a distinction between *scaling up*, *scaling out* and *scaling down*. These people use the term scaling up for passing experience, knowledge, impact and effects higher up the hierarchy of an organisation or a society. Scaling out refers to passing experience, knowledge, impact and effects to other parties with whom is no hierarchical relation, for example to other farmers or

to other regions. Scaling down means applying the knowledge that is available on higher levels of the hierarchy on lower hierarchical levels, for example when an international development agency introduces the concept of a Farmer Training School in a region (IIRR, 1999).

A follow-up to this workshop was titled “Going to Scale” and was held in the Philippines in 2000 (IIRR, 2000). The latter workshop divided the approaches to scaling up in two groups: *horizontally scaling up* and *vertically scaling up*. Horizontally scaling up corresponds with scaling out: passing experience, knowledge, impact and effects to other parties with whom is no hierarchical relation. Vertically scaling up means passing experience, knowledge, impact and effects higher up the hierarchy of an organisation or a society.

### *Reflection on current scaling up approaches*

Above, an overview is presented of how scaling up is approached by people and organisations. Unfortunately, the literature remains complex. Many publications draw lessons from case studies. In some cases, this happened in workshops where a number of cases were presented. Relevant questions and lessons learnt were grouped, common stages were described and useful strategies were identified. Examples of publications that use case studies are Gillesie (2004), IIRR 2000 and Gündel et al. 2001, the latter two describe workshops.

The reason that the literature remains complex is that scaling up occurs under a great variety of conditions and involves policy, research as well as extension. Where conceptual frameworks appear, these contain a wide variety of different items that where found in the various case studies.

An additional problem is that the literature presented above does not provide much insight in making priorities: a number of approaches are presented but the effectiveness and efficiency of these approaches is not compared. On the contrary, the literature breathes the atmosphere of “let a thousand flowers bloom”. For example, Uving and Miller (1994) valued the variety in approaches. Another example is the bottom-line definition presented during the “Going to Scale” workshop. Scaling up was defined as “more quality benefits to more people more quickly more equitably more lastingly over a wider geographical area” (IIRR, 2000). This is simply telling that more things should be made better.

Has scaling up become a catchphrase? This question is relevant because of the large amount of definitions and approaches to scaling up. However, the need to reach more people is genuine. As the introduction of this article demonstrated, the number of people who need agricultural innovation is very large while budgets for rural extension are not expected to rise significantly. Donors are demanding more and more that their money is used to make a difference. The literature presented above does not explain why certain innovations successfully benefited many people over a wide geographical area while other attempts to scale up beyond a pilot project failed.

Moving beyond the catchphrase requires a vision on how to scale up without increasing the resources needed. This requires an other type of classification than the ones that were presented above as more insight in the limitations of the different types of scaling up is needed. Such classification should not be based on the way in which scaling up is discussed by people and

organisations, but it should be based on the efficiency of improving the lives of many rural poor with limited resources. Economic and management sciences deal with prioritisation and have developed a number of concepts to describe scale increases. The next section presents economic approaches to scale.

## Economic approaches to scale

Three concepts are frequently used to describe what happens when the scale of a system, a process or a component is changed. These concepts are *diminishing returns*, *returns to scale* and *scalability*. The concepts of diminishing returns and returns to scale are part of standard undergraduate economic theory. Scalability is a concept that is often used in ICT designs and in business plans. Below, the production function is used to define these three concepts and the role of these concepts in the agricultural debate is discussed. Finally, the three concepts are compared.

### *Production function*

The scale of a system, a process or a component is changed when throughput levels are changed. In standard economic theory, the concepts of diminishing returns and returns to scale are often explained by means of a production function that shows how the relation between input and output changes when the scale is changed (e.g. by Katz and Rosen,1991). Scalability can be described in a similar way (Singh 2001).

The production function represents production within a fixed period of time by $Q = F(L, K)$. Q stands for the quantity produced or output. This may be a physical quantity but it may also refer to services. L stands for Labour and K stands for Capital. L and K are the so called production factors or input. With F is meant that the quantity produced is a function of Labour and Capital. F is the quality of the production process and is approached as a black box. In an abstract sense, F is often called “technology” but this may also refer to the organisation used.

In order to define the concepts of diminishing returns, returns to scale and scalability, the scale is increased in different ways and the behaviour of the production function is described for each of these concepts.

### *Diminishing returns*

Diminishing returns refer to a situation in which an additional unit of a single variable input yields a decreasing amount of additional output. For example, if you keep adding labour to a production process without changing the amount of capital, you may reach a point beyond which each additional unit of labour yields less and less additional output. Or if you keep adding nitrogen to a crop without changing other factors that influence the yield, you'll reach a point beyond which each additional unit of nitrogen yields less and less units of output. In such a case, the Law of Diminishing Returns applies and
$F(2L, K) < 2 F(L, K)$.

All agronomists and agricultural economists are familiar with the Law of Diminishing Returns as agricultural science has traditionally focussed on scarce production factors. The concept was first put forward by the French economist and statesman Turgot in the 18$^{th}$ century. In the 19$^{th}$ century, the concept was elaborated and popularised by Johann

Heinrich von Thünen, Thomas Malthus and David Ricardo. The concept of Diminishing Returns played a role in determining how to make optimal use of a scarce resource. The Law of Diminishing Returns is reflected in the Law of the Minimum by Von Liebig (1855), the Law of the Optimum by Liebscher (1895) and the Law of Constant Activity by Mitscherlich (1924; De Wit 1992) that describe the relation between production factors and yield.

The famous prediction by Malthus (1798) that population growth would outrun food production was based on the focus on land as a scarce resource. Malthus believed that there were two ways in which agricultural production could be increased: cultivate more land or use existing farmland more intensively. In both cases, the marginal returns of agriculture would diminish. According to De Wit (1992), the prediction of Malthus did not happen because the decrease in marginal returns where compensated by technological improvements.

### *Returns to scale*

Increasing returns to scale occur when the amount of total output rises more than proportionately with an increase of all production factors. If this occurs, then $F(2L, 2K) > 2 F(L, K)$. This may occur if increasing the scale of production results in producing more efficiently. Decreasing returns to scale are also possible. In that case, the amount of total output rises less than proportionately with an increase of all of the production factors. This happens for example when the costs of management increase more than proportionally when the scale of production is increased. If this occurs, then $F(2L, 2K) < 2 F(L, K)$. Returns to scale may also be constant. In that case, the amount of total output rises proportionally with an increase in all of the production factors. In this case, $F(2L, 2K) = 2 F(L, K)$.

Returns to scale and the related concept of economies of scale are used to determine the ideal firm size. If a firm is too small, the firm is not efficient. A firm can also be inefficient because it is too large. In agriculture, where a farm has usually multiple purposes, the term “firm” may refer to either farm or area cultivated. When farmers unite and establish a cooperative, they may enjoy scale advantages caused by increasing returns to scale.

When the arena of agricultural innovation is considered, returns to scale play two roles. Firstly, smallholders and large farmers differ in their ability to adopt technology and part of this difference can be explained by the concept of returns to scale. Differences in development patterns between small farmers and large farmers have been part of the agricultural debate for a long time. Such contributions to the agricultural debate have often been linked to political ideologies (e.g. Lenin, 1899). In current agricultural research, it is widely recognised that the scale of agricultural production influences the adoption of technology as smallholders often lack control of production factors like land, labour, water and credit to take advantage of new technologies. A large farmer has the money to buy all the input at the right time while access to credit is more limited for smallholders.

Secondly, processes in the institutions involved in extension may be subject to returns to scale. The concept of returns to scale is useful in order to determine at what scale a technology can be disseminated at the cheapest price per farmer. For example, Garret (2001) revealed significant economies of scale for county extension offices in Kansas, USA. Anderson and Feder (2003) mentioned

a loss of economies of scale when rural extension services are decentralised. They described that decentralisation involved a trade-off between greater accountability and services to farmers on the one hand and loss of economies of scale on the other hand.

### *Scalability*

Scalability is a concept that is used in designs in telecommunications and software engineering as well as in business plans to describe designs that are developed with scaling in mind. Scalable systems, components or processes do not need to be replaced or changed when the scale is increased. Scalability refers to the extent to which a system, a component or a process is scalable.

Suppose software is part of the production function F and F is subject to constant returns to scale so that Q = F(L, K) and F(2L, 2K) = 2 F(L, K). If we break software out as a separate input, we can write the production function as Q = G(L, K, S) in which S stands for software. G stands for a different production function depending on other technology than software. As the software has already been written, increasing the amount of labour and capital does not require more software, so G(2L, 2K, S) = 2G(L, K, S). In this case, the production factor S is scalable (Sing 2001). The software S may also be used in other, similar firms without changing or redesigning it.

With the exception of scalability in rural ICT, no significant literature was found that mentioned scalability in the context of agricultural development or rural extension. While scalability has not been mentioned as such, it is highly related to the question of relevance of technology. If the software S is not relevant for another firm, it can not be used without at least adapting it and S is not scalable to this other firm. It has been stated by many authors that technological innovations have not been adopted because these where not relevant for smallholders. For example, Van der Ploeg (1991) mentioned a 'horizon of relevance' beyond which a design is no longer relevant. Oasa (1981) described that agricultural technologies are often designed assuming the social, economic and ecological context of larger farmers. These farms are often located on betters soils, are better connected to markets and have better access to water, information, labour and credit. So a design is scalable over a range of farmers who are able to meet the requirements of that design. Within this range, the design can be scaled up while meeting local demands. For this reason, scalability is an intersection of the contextualist and universalist principles.

Scalability is not only relevant for the design of technology, but also for the mechanisms that lead to its dissemination. Farmer to farmer contact is often seen as a successful mechanism to disseminate knowledge. This mechanism does not need to change if more farmers adopt a technology: The more farmers adopt a technology, the more farmers tell other farmers how to use it – especially when farmers are proud on the results. This way, the costs of dissemination do not rise while large amounts of farmers are reached, nor does the mechanism of dissemination need to be replaced or changed when the scale is increased.

So while the concept of scalability has not been mentioned as such in literature, the concept is able to explain why some designs and dissemination methods have been successful.

***Comparison between diminishing returns, returns to scale and scalability***

The concepts of diminishing returns, returns to scale and scalability describe a trade-off between the effort that is made and the output of a system, a process or a component. The Law of Diminishing Returns describes a trade-off between a single production factor and output. Returns to scale describe the trade-off between the quantity of input of all production factors and the output. Scalability is used to describe the range in which a system, component or process can be used. As a scalable system, process or component does not need to be changed, increased or replaced in order to increase the output, the costs are not higher than its creation within this range.

The concept of scalability offers an advantage over the concepts of diminishing returns and returns to scale. If an innovation that is subject to diminishing returns is scaled up, there is a point beyond which costs outweigh benefits. The same holds true for innovations that are subject to decreasing returns to scale. Increasing returns to scale are more attractive as the additional costs decrease when the scale is increased. Unfortunately, processes that are subject to increasing returns to scale typically have an optimum beyond which the process is subject to constant or decreasing returns to scale. Scalable solutions can be applied again and again within their horizon of relevance without having to be adapted or redesigned.

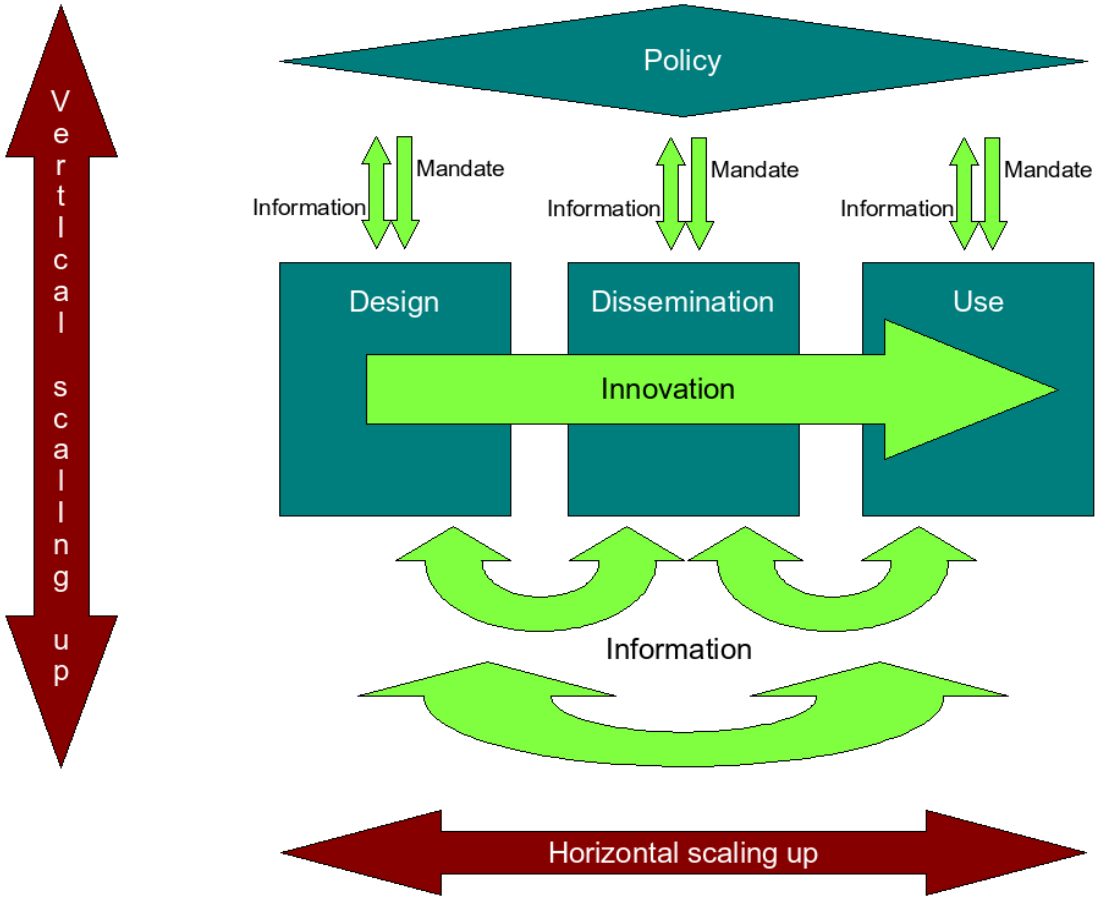
## A conceptual framework for understanding the nature of scale increase in agricultural innovation

The proposed conceptual framework consists of two parts. The first part divides the process of agricultural innovation in 4 sub processes: *policy*, *design*, *dissemination* and *use*. The second part shows that the application of a design and the sub processes dissemination and use are subject to three types of scale increase, being either *diminishing returns*, *returns to scale* or *scalability*. The framework can be used to provide insight in the consequences of different options when decisions on scaling up are required.

**Table 1.** ***Comparison between the concepts of diminishing returns, returns to scale and scalability.***

| *Concept* | *Situation* |
|---|---|
| diminishing returns | The quantity of one production factor is changed |
| returns to scale | Total throughput changes including all production factors |
| scalability | A production factor does not need to change in order to change the throughput |

**Fig. 1** ***The process of agricultural innovation***




***Process oriented model of agricultural innovation***

The proposed conceptual framework considers agricultural innovation as a process. Agricultural innovation is introducing new insights, new technologies, new organisational arrangements, new networks etc. into economic use in agriculture. This process is divided in 4 sub processes: policy, design, dissemination and use.

Design is both the process and the result of creating a new insight, a new technology, a new organisational arrangement, a new network etc. Dissemination is the process of spreading a design to users. Use is any process that is changed by agricultural innovation. Design, dissemination and use interact by sending information to each other. Policy is decision making. It provides mandates to design, dissemination and use and the latter three processes exchange information with policy. Figure 1 shows the relation between these processes.

While Figure 1 shows a design that moves from the design process via dissemination to the end users, this is not the linear, supply driven model of agricultural innovation. The debate between the linear, supply driven models and the demand driven models of agricultural innovation is based on system analysis. In such an analysis, the relations between the actors and organisations involved are studied. A

**Table 2.** ***Types of scale increase within agricultural innovation***

| | ***diminishing returns*** | ***returns to scale*** | ***scalability*** |
|---|---|---|---|
| ***design*** | When more farmers use the technology, the benefits for each additional farmer become lower and lower. | The efficiency of the technology changes when it is used by more farmers. | A design can be used within a range of farms. |
| ***dissemination*** | Doing more of the same results in less and less additional farmers adopting a technology. | Doing more of the same changes the price of reaching a farmer. | A mechanism or agent of change allows more and more farmers to be reached without additional costs. |
| ***use*** | Applying more of the same input, results in less and less additional output. | Productivity changes more than proportionally when the farm size or area cultivated is changed. | A production factor can have a wider effect without increasing costs. |

process is a series of events, transformations or activities that lead to a certain aim. In contrast to the linear model of agricultural innovation, the sub processes presented in Figure 1 can be performed by various actors and different kinds of actors can collaborate in the same process. For example, the model in Figure 1 does not tell whether design is performed by researchers, extension officers, policy makers or farmers. By focussing on processes without including procedures (procedures describe *who* does *what*), the conceptual framework becomes independent from locally specific innovation systems and the conceptual framework can be applied in a wide range of different circumstances.

### *Matching the process of agricultural innovation to types of scale increase*

Any change of scale within the application of a design, dissemination and use is subject to either diminishing returns, returns to scale or scalability. This results in a total of 9 situations that are described in Table 2.

The production function Q = F(L, K) has a different meaning within each of these processes. Within the process use, Q simply refers to the quantity produced on a farm, on an area cultivated or by a firm in the agro-industrial chain while F is the factor that is changed by innovation. In dissemination, Q refers to quantities like the number of farmers who adopt a new technology. When design is concerned, we need to break out the design as a separate input

and write the production function as
Q = H(L, K, D) in which D stands for the design and H for a different production function in which the design is not included.

### *Examples*

This section illustrates how the application of a design, dissemination and use of technology or organisational arrangements can be subject to diminishing returns, returns to scale or scalability by means of examples.

When the use of agricultural technology or organisational arrangements is considered, changing the scale has to do with optimisation. An example of technology use that is subject to diminishing returns is nitrogen fertilisation: if you keep adding nitrogen to a crop without changing other factors that influence the yield, you will reach a point beyond which each additional unit of nitrogen yields less and less units of output. Cooperatives are an example of increasing returns to scale: By cooperating, some farmers can buy a tractor which they could not afford at the scale of their own farm. An example of the use of a scalable technology in agriculture is on-line weather reports: more farmers can use these without increasing the costs.

Dissemination mechanisms can be subject to diminishing returns. Evenson (1998) hypothesised that increasing the number of extension workers per farmer in Kenya was subject to diminishing returns. In another article, Evenson (1997) wrote that the effect of extension on yield is subject to diminishing returns when actual yields near best practice yields. An example of a dissemination method that is subject to returns to scale is printing manuals: the more manuals are printed, the lower the price per manual. The farmer to farmer mechanism, in which dissemination depends on farmers who share their experience, is highly scalable: the more farmers have experience with a technology, the more farmers are able to share their experience.

Oasa (1981) and Van der Ploeg (1991) described that an horizon of relevance was assumed when technological packages were designed. Assuming that the farmers who benefit most from these packages adopt these packages first, applying the technology to more farmers results in less and less benefits. In this case, the design of the technology is subject to diminishing returns. Integrated Pest Management or IPM performs better when more farmers in a region use this technology because pest infestations from neighbouring fields diminish. The design of this technology is therefore subject to increasing returns to scale. The zero tillage technology is an example of a scalable design. At first, the technology was scalable within the ecological circumstances of the South of Brazil. The technology had to be adapted to the circumstances of the Cerrado biome before it could be used there. Eventually, a new technology was designed that was scalable within this region. For this reason, the zero tillage explosion in the Cerrado occurred a few years after the zero tillage explosion in the South of Brazil (Landers, 1999 and 2001).

### *Policy*

Policy is not included in Table 2 but makes decisions on the other sub processes. The framework provides insight needed for making decisions on scaling up. When a decision on scaling up is made, it should be considered to what extend the system, process or component at hand is subject to diminishing returns,

returns to scale or scalability. If scale increases are considered a problem, three options are available:

- *Increase budgets*
  Do not change the organisation and technology involved and accept the trade-off between costs and benefits. This means that more resources are needed in order to scale up.
- *Change the dissemination*
  Use other mechanisms to disseminate the innovation, leading to a better trade-off between costs and benefits.
- *Change the design*
  Change the design of the technology involved or change the organisation to improve the trade-off between investment and result.
- *Change the context*
  Policy by governmental organisations can also affect the context of use of technology directly by making laws and regulations.

## Concluding remarks

According to the proposed conceptual framework, the nature of scale increase in agricultural innovation depends on whether the application of a design, the dissemination mechanisms and use are subject to diminishing returns, returns to scale or scalability. In each case, a different kind of trade-off can be expected between the effort made and the resulting increase in scale.

The proposed conceptual model focusses on the process of agricultural innovation and does not describe the actors, institutions and the relations between them in concrete situations. This makes this conceptual framework scalable towards a wide range of circumstances, but in each situation it should be considered carefully to what extend the framework applies.

The conceptual framework builds on the fact that systems, processes and components are subject to diminishing returns, returns to scale or scalability. The exact causes of this behaviour are not explained. In the production function Q = F(L, K), F is the quality of the production process and F is approached as a black box. A concrete situation in which a concrete technology, a new organisation arrangement, a new insight etc. is introduced should be analysed carefully before conclusions on the nature of scale increase are drawn.

If the nature of scale increase depends on the technology or organisational arrangements involved (F), then the nature of scale increase is already defined during the design process. This supports the view of Tekelenburg (2002), Röling et al. (2004) and Hounkonnou (2006) that scaling up should be included as a pre-analytical choice. Scaling up as an afterthought is risky as its success depends on coincidence.

The concept of scalability offers an advantage over the concepts of diminishing returns and returns to scale as scalable innovations do not need to be replaced or changed when the scale is increased. For this reason, I expect that this concept is likely to play a larger role in agricultural innovation in the near future. Already, the scalable Farmer to Farmer approach has become more popular. As the concept of scalability is derived from telecommunications and software engineering, more scalable solutions are likely to become available when more ICT is used in agricultural extension.

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